Prompt photon hadroproduction in the k_T-factorization approach

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Abstract. We study the production of prompt photons at high energy in the framework of the k_T-factorization approach. The amplitude for production of a single photon associated with quark pair in the fusion of two off-shell gluons is calculated. Theoretical results are compared with the Tevatron data.

Keywords: QCD, pp collisions, k_T-factorization, prompt photon
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INTRODUCTION

The production of prompt photons in hadron-hadron collisions at the Tevatron is a subject of intense studies (see, for example, [1]). At the leading order of QCD, prompt photons can be produced via quark-gluon Compton scattering or quark-antiquark annihilation and so, the cross sections of these processes are strongly sensitive to the parton (quark and gluon) content of a proton. Besides that the events with an isolated photon are an important tool to study hard interaction processes since such photons emerge without the hadronization phase. In standard QCD, the disagreement between experimental data at the Tevatron [2, 3, 4] and theoretical description (see Refs. in [1]) is attributed usually to the initial-state soft-gluon radiation or to the intrinsic nonperturbative transverse momentum k_T of the incoming partons.

In the framework of the k_T-factorization approach [5] the treatment of k_T-enhancement and gluon emission is more reasonable. In this approach the transverse momentum of incoming partons is generated in the course of non-collinear parton evolution of the BFKL type [6]. In paper [7] to analyse the data [2, 3, 4] the proper off-shell expressions for partonic matrix elements and KMR unintegrated parton densities [8] have been used. An important component of the calculations [7] is using the unintegrated quark distributions in a proton. At present these densities are available in the framework of KMR approach only. It makes difficulties for the invistigation of dependence of the calculated cross sections on the non-collinear evolution scheme in the k_T-factorization approach.

In our paper [9] we have used a different way. Instead of using the unintegrated quark distributions and the corresponding quark-gluon fusion and/or quark-antiquark annihilation cross sections we have calculated off-shell matrix element of the $g^*g^* \to q\bar{q}\gamma$ subprocess, having hope for operating in terms of the unintegrated gluon densities only. But, first of all, these matrix elements cover only the sea quark contribution. However, the contribution from the valence quarks is significant only at large x, and

therefore can be safely taken into account in the collinear LO approximation as an additional one. Secondly, this idea can only work well if the sea quarks appear from the last step of the gluon evolution. This method does not apply to the quarks coming from the earlier steps of the evolution, if they are, and it is not evident in advance, whether the last gluon splitting dominates or not. The goal of out study here is to clarify this point in more detail than in [9].

THEORETICAL FRAMEWORK

Here we use the specific property of the KMR scheme [8] which enables us to discriminate between the various components of the quark densities. We start from the leading order $\mathscr{O}(\alpha)$ subprocess "$q^* + q^* \to \gamma$", and then divide it into several contributions which correspond to the interactions of valence quarks $q_v(x, \mathbf{k}_T^2, \mu^2)$, sea quarks appearing at the last step of the gluon evolution $q_g(x, \mathbf{k}_T^2, \mu^2)$, and sea quarks coming from the earlier steps $q_s(x, \mathbf{k}_T^2, \mu^2)$.

The KMR approach represents an approximate treatment of the parton evolution mainly based on the DGLAP equation and incorporating the BFKL effects at the last step of the parton ladder only, in the form of the properly defined Sudakov formfactors $T_q(k_t^2, \mu^2)$ and $T_g(k_t^2, \mu^2)$. These formfactors already include logarithmic loop correction. In this approximation, the unintegrated quark distributions are given by

$$f_q(x, \mathbf{k}_T^2, \mu^2) = T_q(\mathbf{k}_T^2, \mu^2) \frac{\alpha_s(\mathbf{k}_T^2)}{2\pi} \times$$
$$\times \int_x^1 dz \left[P_{qq}(z) \frac{x}{z} q\left(\frac{x}{z}, \mathbf{k}_T^2\right) \Theta(\Delta - z) + P_{qg}(z) \frac{x}{z} g\left(\frac{x}{z}, \mathbf{k}_T^2\right) \right], \tag{1}$$

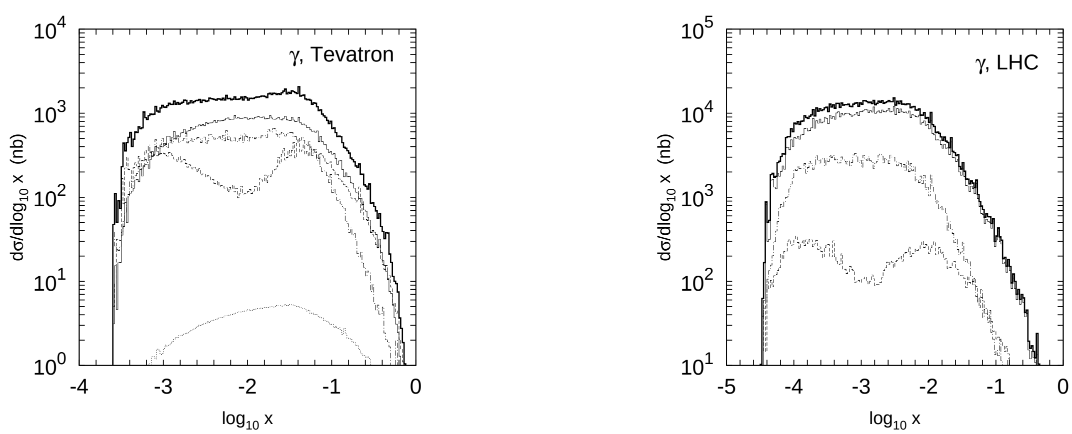

FIGURE 1. Differential cross section of prompt photon production at the Tevatron and LHC as a function of $\log_{10} x$. Different histograms correspond to different subprocess (see text).

where $P_{ab}(z)$ are the usual unregularised leading order DGLAP splitting functions, and $q(x,\mu^2)$ and $g(x,\mu^2)$ are the conventional (collinear) quark and gluon densities. Modifying Eq. (1) in such a way that only the first term is kept and the second term omitted, we switch the last gluon splitting off, thus excluding the $q_g(x,\mathbf{k}_T^2,\mu^2)$ component. Additional conditions which preserve our calculations from divergences and, also, the isolation cuts which suppress the contribution of fragmentation component in the photon production have been discussed in [9].

NUMERICAL RESULTS

In Fig. 1 we show a comparison between the different contributions to the inclusive

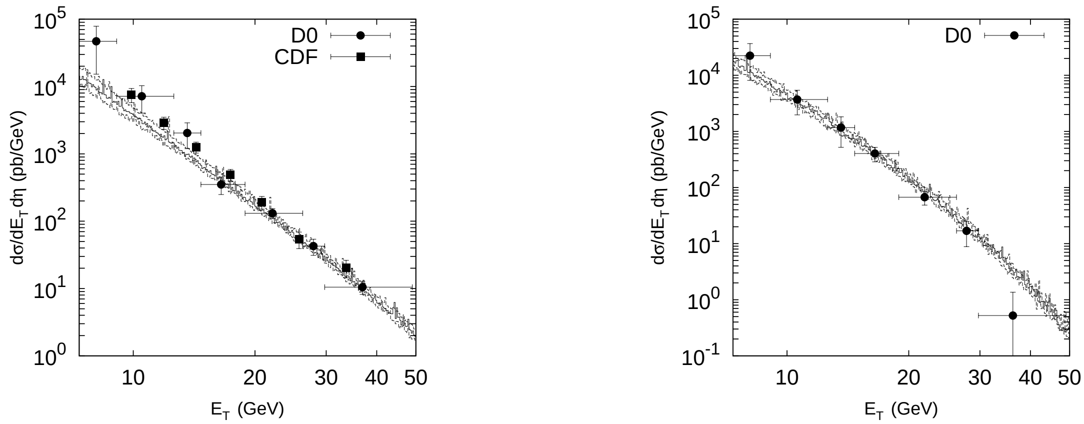

FIGURE 2. $d\sigma/dE_T d\eta$ of the inclusive prompt photon production at $\sqrt{s} = 630$ GeV in the region $|\eta| < 0.9$ (left panel) and $1.6 < |\eta| < 2.5$ (right panel). Solid histogram corresponds to the hard scale $\mu = E_T$, the upper and the lower histograms correspond to the usual variation of the hard scale μ.

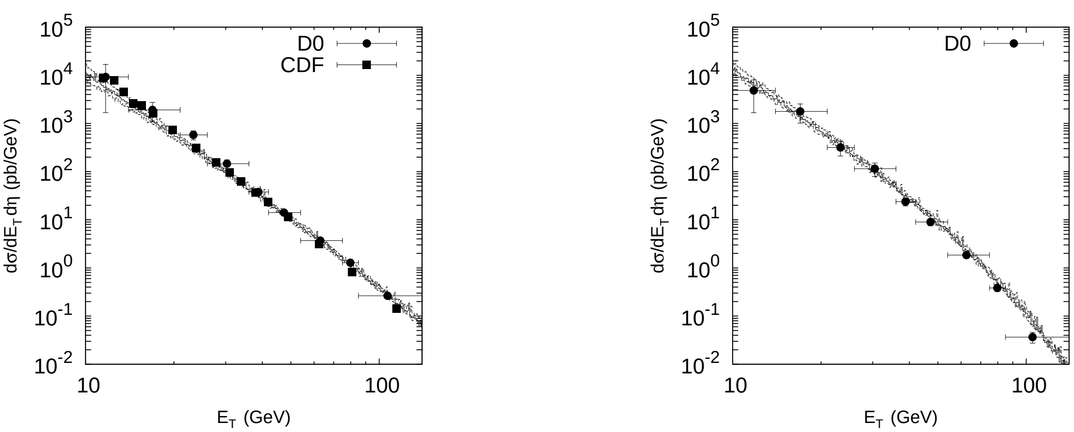

FIGURE 3. $d\sigma/dE_T d\eta$ of the inclusive prompt photon production at $\sqrt{s} = 1800$ GeV in the region $|\eta| < 0.9$ (left panel) and $1.6 < |\eta| < 2.5$ (right panel). The notation of the histograms is as in Fig. 2.

cross section of the prompt photon production at Tevatron and LHC energies. The solid, dashed and dotted histograms represent the contributions from the $g^*g^* \to \gamma q\bar{q}$, $q_v g^* \to \gamma q$ and $q_v\bar{q}_v \to \gamma g$ subprocesses, respectively. The dash-dotted histograms represent the sum of the contributions from the $q_s g \to \gamma q$, $q_s\bar{q}_s \to \gamma g$ and $q_v\bar{q}_s \to \gamma g$ subprocesses. Below we denote it as "reduced sea" component [1]. The thick solid histograms represent the sum of all contributions. We see that the gluon-gluon fusion is an important production mechanism of the prompt photon production both at the Tevatron and LHC conditions. At the LHC, it gives the main contribution to the cross section. approximately 30% contribution to the total cross section of prompt photon production at Tevatron and approximately 20% contribution at LHC.

Figs. 2 and 3 confront the double differential cross sections $d\sigma/dE_T d\eta$ of the prompt photon production calculated at $\sqrt{s} = 630$ and 1800 GeV with D⊘ [2] and CDF [3] data. One can see that our results agree very well with the Tevatron data.

In summary we have studied the production of prompt photon in hadronic collisions at high energies in the k_T-factorization approach of QCD. The central part of our consideration is off-shell gluon-gluon fusion subprocess $g^*g^* \to \gamma q\bar{q}$. The contribution from the valence quarks has been taken into account additionally. We demonstrate in the KMR approximation that important contribution to total cross sections of process under consideration also comes from the sea quark interactions.

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[1] This component has not been taken into account in [9].